ECONNECT International Workshop
Restoring the web of life

4-6 November 2009
Grenoble, France

Quantitative methods for analyzing and integrating connectivity in landscape planning

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Integrating connectivity in landscape planning…

1) Which main approaches are available?
2) Should we measure only connectivity between habitat patches?
3) Is connectivity always the best conservation strategy?
4) An example of application in NE Spain
5) *Which operational tools are available?*

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Simple spatial metrics

Easily computed with any GIS or widespread programmes for the calculation of landscape pattern metrics (e.g. Fragstats)

Many of them only consider structural connectivity or deal with functional connectivity in a very crude / primitive way.

Examples: Nearest-neighbour metrics, connectance index, patch cohesion, buffer metrics, etc.

Use:

Only for exploratory and descriptive analysis in general.

Not usable for decision making.

In some cases have suffered from particularly wide abuse.

Spatially explicit population (metapopulation) models

Biologically detailed. They consider the population dynamics resulting from birth, morality, emigration and immigration processes in individual patches.

Use:

Need to be used when the connectivity analysis requires an assessment of spatiotemporal population trends and persistence, dealing with demographic dynamics such as colonization and extinction events, demographic growth, *etc.*

Constrained by their data requirements. Limited to small study areas & scientific experiments (Calabrese and Fagan, 2004).

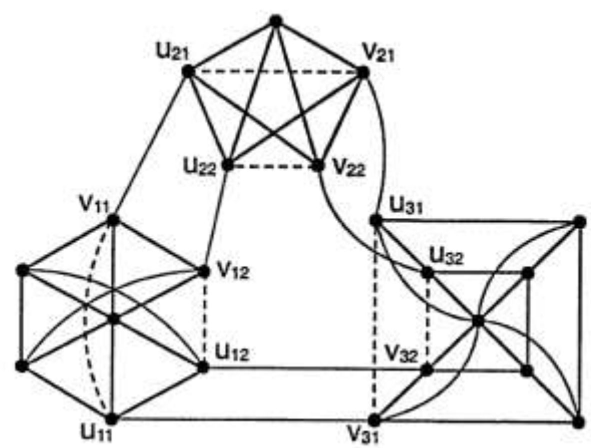
Graph-based approaches

Graph = set of nodes (habitat units) and links (connections).

Definition of nodes and links dependent on the degree of detail and the needs and objectives of the analysis.

Exponential growth as an approach to deal with landscape connectivity (Keitt, Urban, Jordan, Saura, Bodin, McRae, etc.).

Widely developed for powerful analyses of the connectivity of many types of networks (communications, internet, social, molecular, etc.).



Graph-based approaches

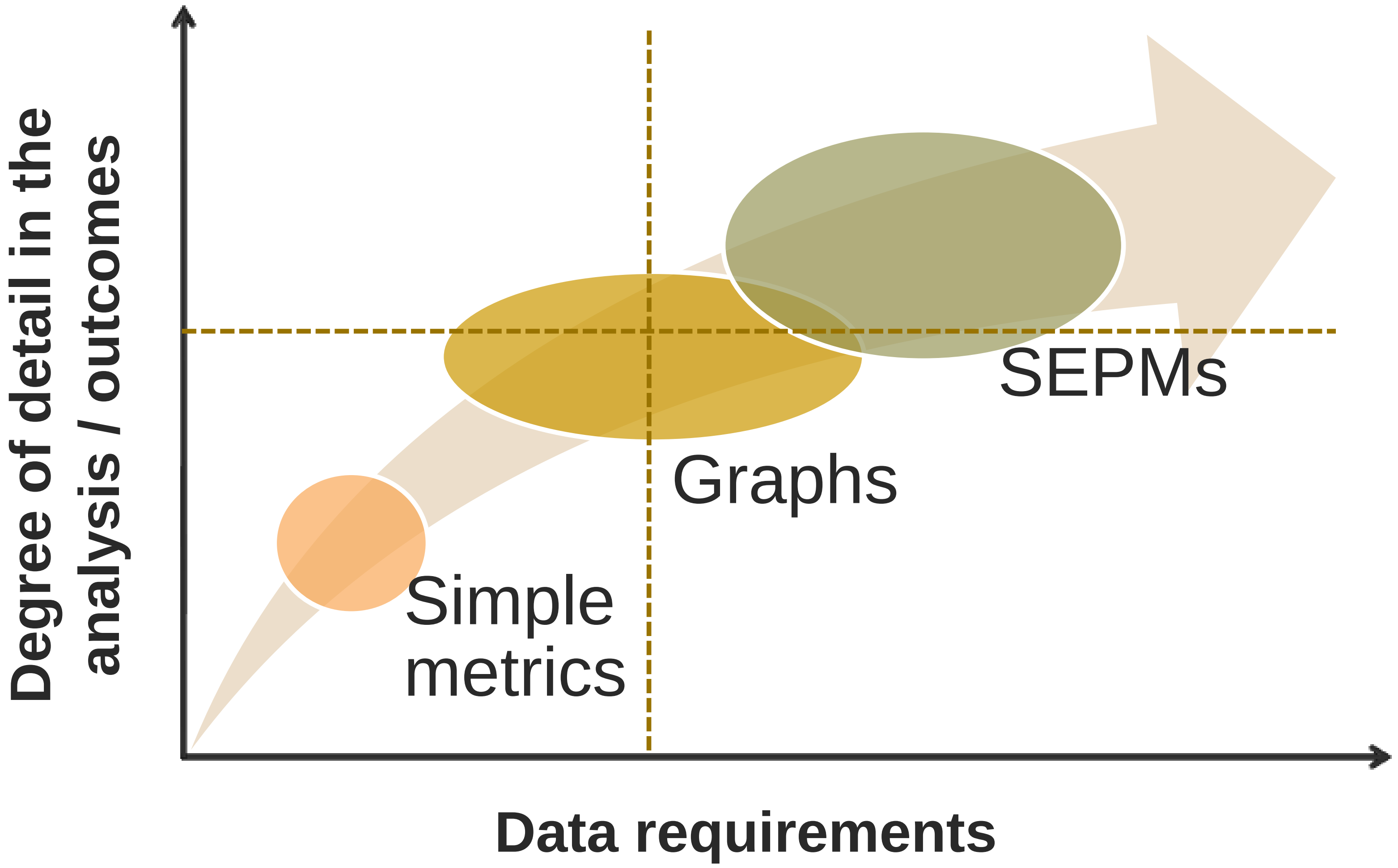
Use:

When you need: (1) a spatially explicit connectivity assessment, (2) that can estimate the value of individual patches and corridors for connectivity, (3) adaptable to different degrees of detail in the available information

When you do not need (1) tracking population dynamics and detailed biological or demographic processes, (2) or simply when such information is not available in practise.

(Some) graph metrics provide similar outcomes to SEPMs in what is required for operational planning (Minor & Urban 2007, Visconti & Elkin 2009).

Balancing data requirements with detail in the outcomes



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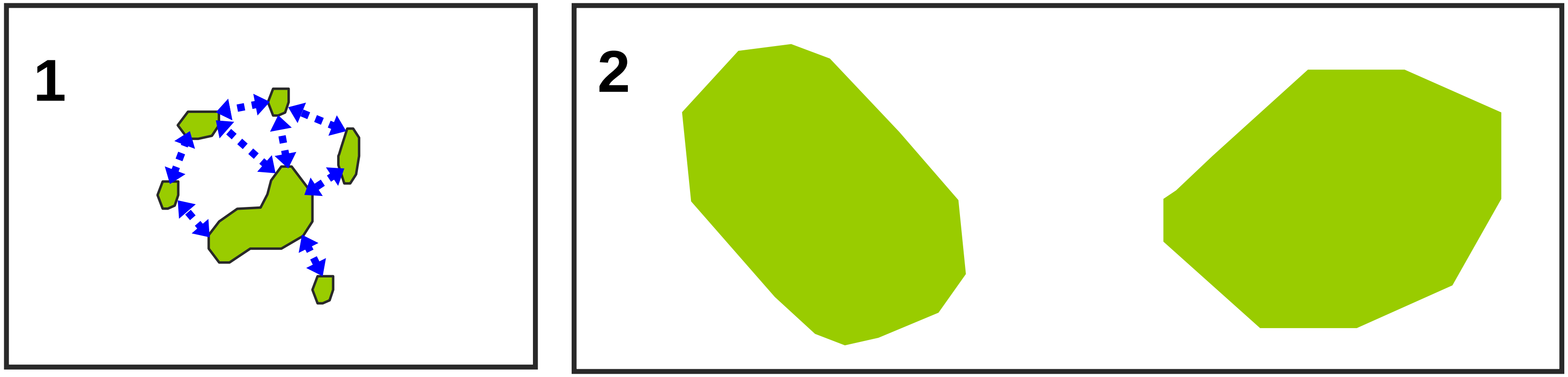
Paradoxes of only measuring connectivity between patches

- ➢ Which landscape is more connected? (1 or 2)
- ➢ Which nodes / habitat patches are more important?



- Need to measure habitat availability at the landscape scale.
- A node / patch is considered as a space where connectivity exists.
- Habitat availability metrics integrate the area within habitat patches (*intrapatch connectivity*) with the area made available by the connections between patches (*interpatch connectivity*).

NEW LANDSCAPE CONNECTIVITY METRICS

- UNWEIGHTED GRAPHS (Pascal-Hortal & Saura 2006)

Integral Index of Connectivity (IIC)

$$IIC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} \frac{a_i \cdot a_j}{1 + nl_{ij}}}{A_L^2}$$

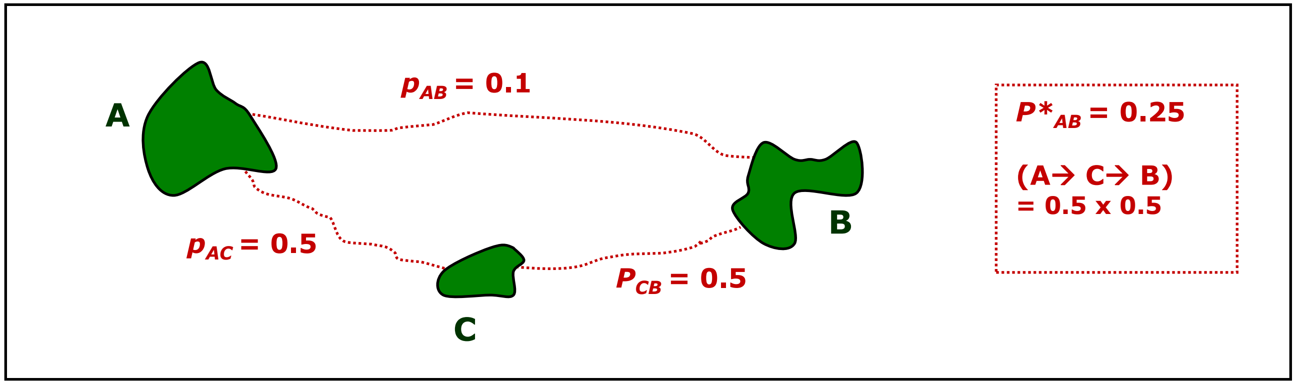
nl = topological distance (no. of links)

- WEIGHTED GRAPHS (Saura & Pascal-Hortal 2007)

Probability of Connectivity (PC)

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \cdot a_j \cdot p_{ij}^{*}}{A_L^{2}}$$

Probability that two points randomly placed within the landscape fall into habitat areas that can be reached from each other given a set of habitat patches and links.



a_i, a_j: patch attribute (area, habitat quality, etc.)

p^*_{ij}: maximum product probability

p^*_{ij} =1 when $i=j$, $p^*_{ij} \geq p_{ij}$

A_L: maximum landscape attribute

Need to support decision making in landscape planning

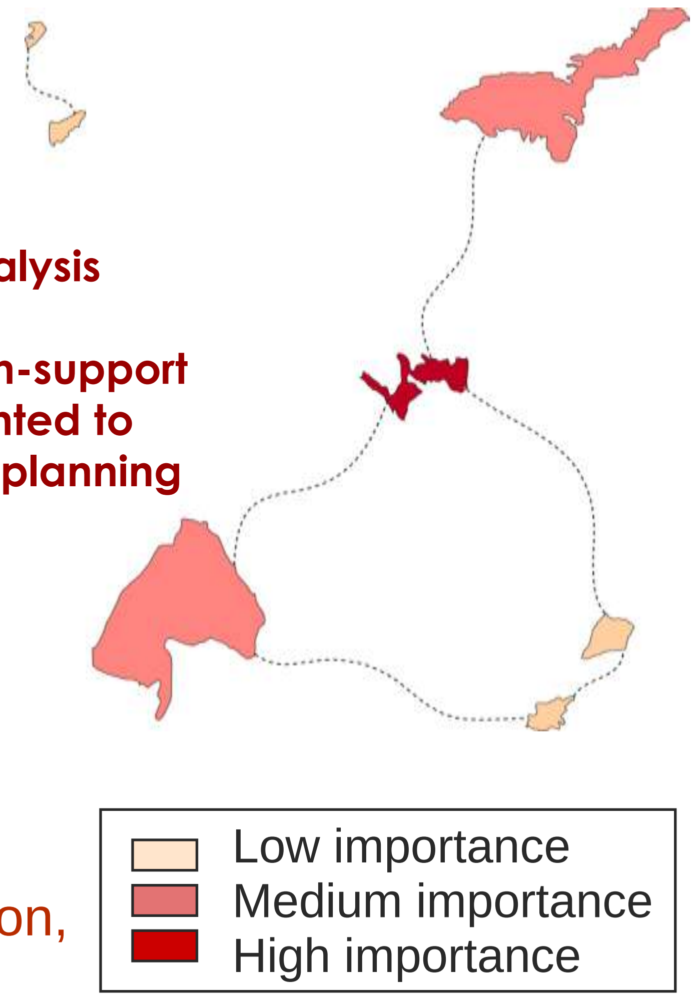
?

Which habitat patches and corridors are more critical for the maintenance of overall landscape connectivity?

- It is not just a descriptive analysis
- It is a decision-support analysis oriented to conservation planning

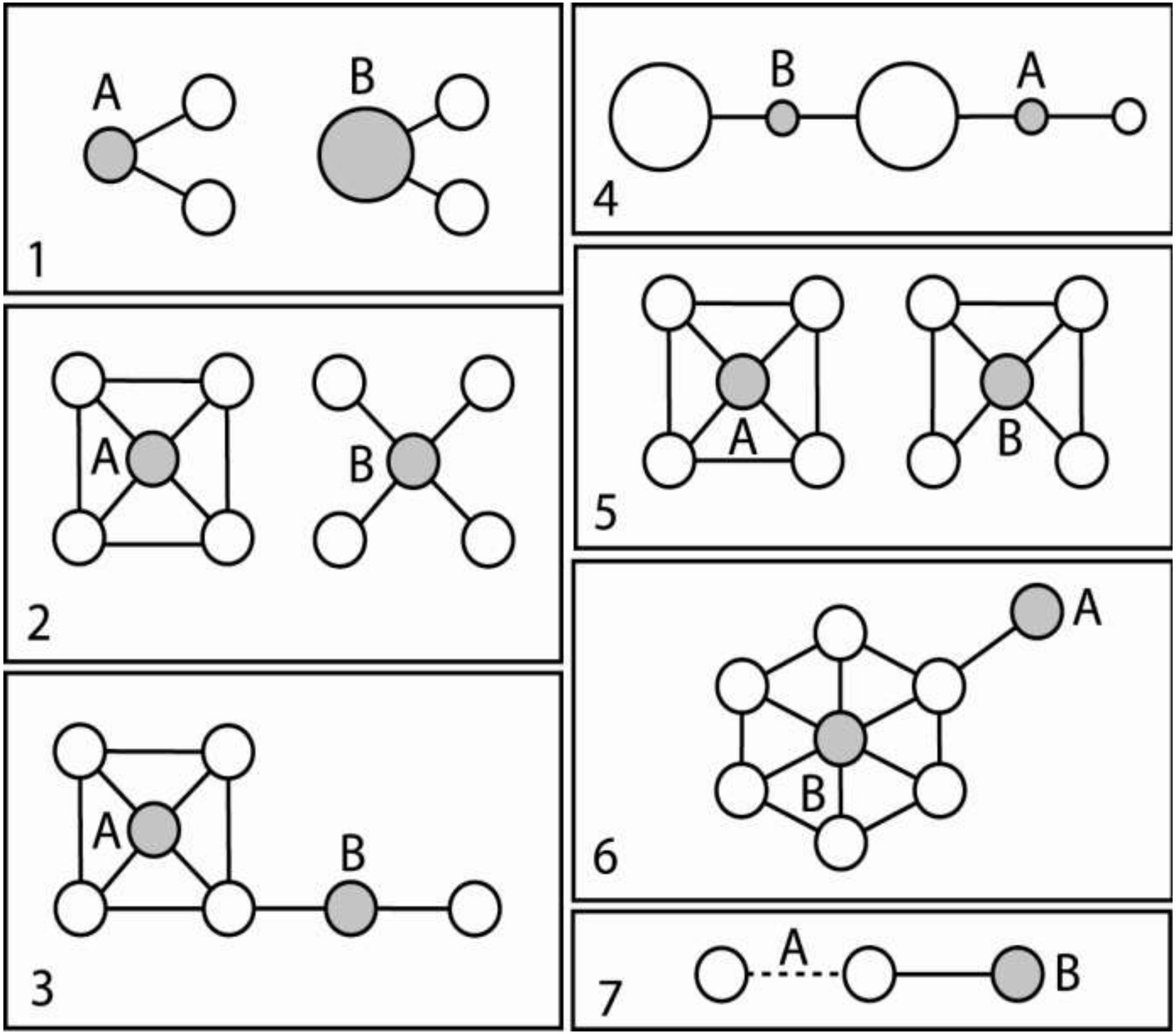
$$dPC_k = 100 \cdot \frac{PC - PC_{remove,k}}{PC}$$

→ Priority sites for conservation, restoration, forestation, etc.



IDENTIFICATION OF THE MOST IMPORTANT (CRITICAL) LANDSCAPE ELEMENTS FOR CONNECTIVITY

(INDEX PRIORITIZATION ABILITIES)

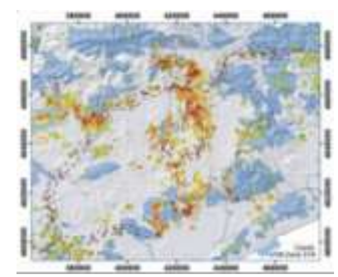


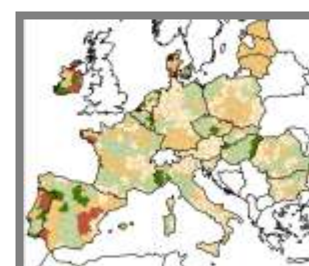
Loosing B
is considered
worse than A

Pascual-Hortal and Saura (2006) *Landscape Ecology*

Conefor Sensinode 2.2: graphs + habitat availability metrics

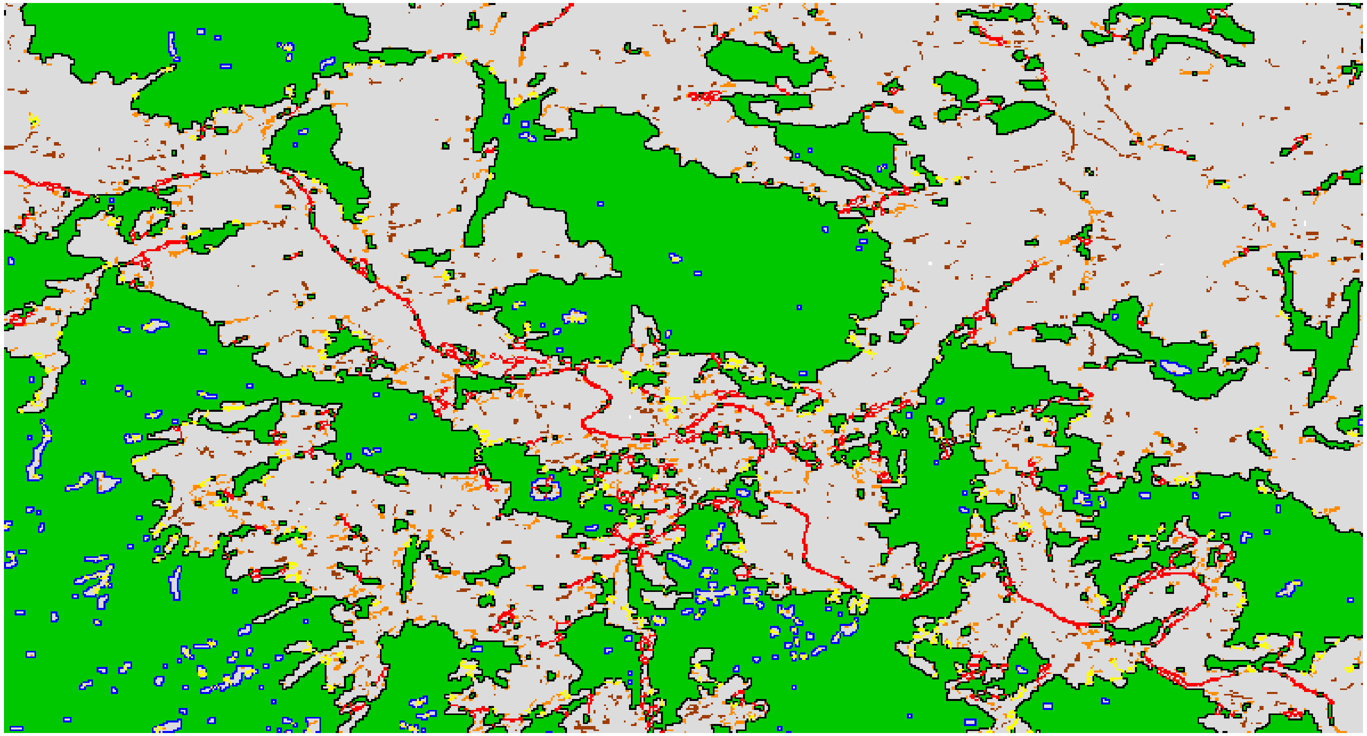
- Freeware & open source: **www.conefor.org**
- Oriented to the identification of critical areas for landscape connectivity (Saura et al.)
- User & planning oriented. GIS extensions
- Applications and case studies (2007-09):
  - Forest and land planning in Spain
  - Genetic diversity & connectivity in USA
  - Forest connectivity trends in EU (EFDAC)
  - Bird species colonization after wildfires in Spain
  - River network connectivity for the otter in Italy
  - Barrier effect of transport infrastructures in China
  - More: Puerto Rico, México, USA, Italy (reforestation)....





Guidos + Conefor: key structural connectors

- Guidos software (Vogt et al.): MSPA bridges
- Conefor Sensinode integration: prioritization of connectors



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Selecting sites for conservation: alternatives and trade-offs

- Criterion 1: Select the best habitat sites by their intrinsic values and characteristics, independently of topology and connectivity.
- Criterion 2: Select those site that enhance most the connectivity between the rest of the sites.

- Trade off: best for 2 implies not getting the best for 1.
- Arbitrary combination of 1 & 2 in the final conservation plan?
- Is really network connectivity a key issue for planning and conservation? When?

Partitioning habitat availability metrics (PC) in three different fractions

$$dPC_k = dPCintra_k + dPCflux_k + dPCconnector_k$$

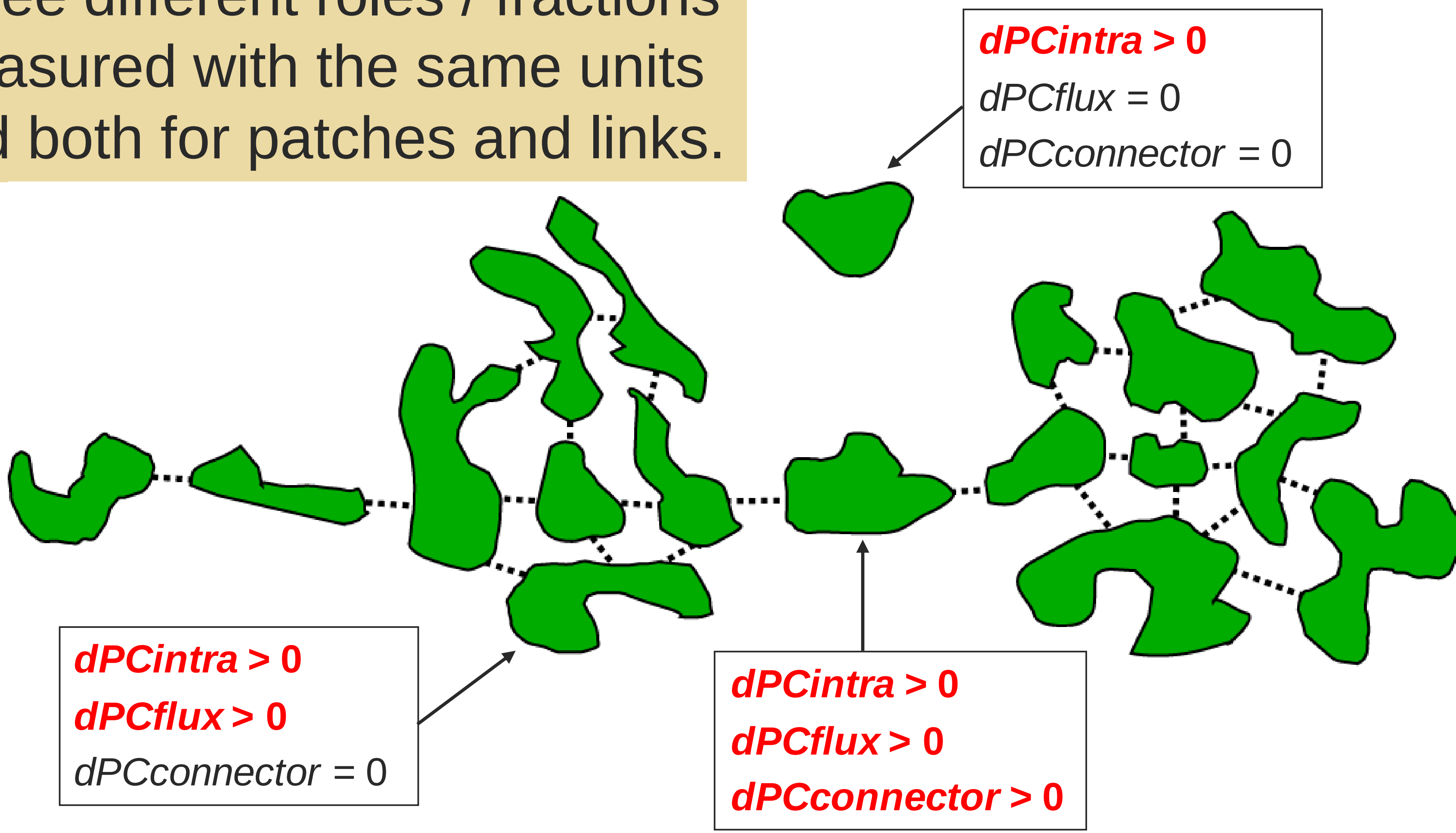
Fraction	Definition / contribution	Network topology?	Intrinsic patch attribute?
dPCintra	Available habitat area provided by patch *k* itself through the area it comprises (**intrapatch connectivity**)	No	Yes
dPCflux	**Flux** of the connections of patch *k* with all the other patches when *k* is either the starting or ending node.	Yes	Yes
dPCconnector	Contribution of *k* to the connectivity between other patches, as **connecting element / stepping stone**. Only if *k* is in optimal path between them. Depends on alternative paths after losing *k*.	Yes (patches + links)	No

Saura & Rubio 2009 *Ecography* (in press)

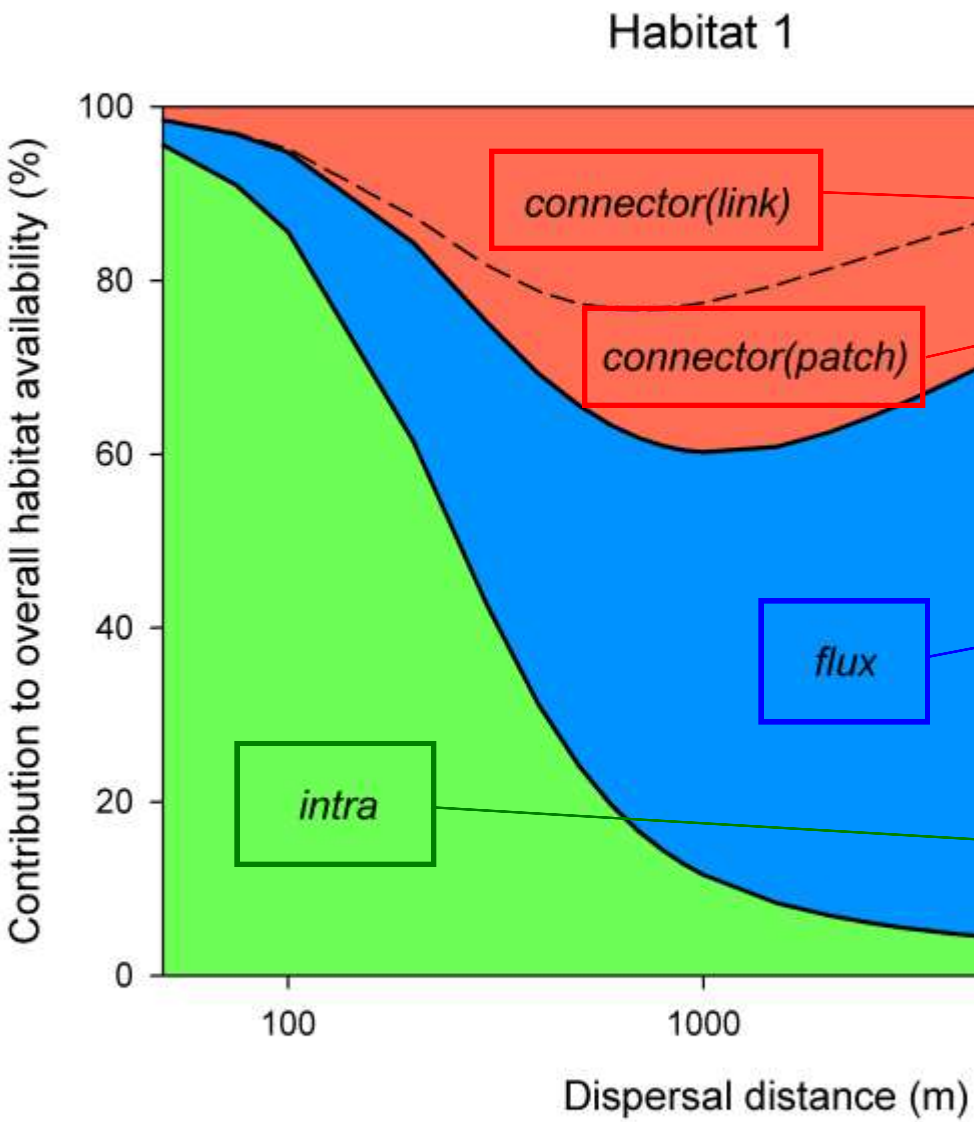
Ways in which a patch can contribute to habitat connectivity and availability

Three different roles / fractions measured with the same units and both for patches and links.

$dPC_k = dPCintra_k + dPCflux_k + dPCconnector_k$



How do the different fractions / roles contribute to overall habitat availability and connectivity?



Largest for intermediate dispersal (stepping stones beneficial for connectivity)

Dominates at large dispersal (no restrictions to connectivity)

Dominates at low dispersal (species confined to the patches where they dwell)

Saura & Rubio (2009) *Ecography* (in press)

When to invest conservation efforts in connecting elements?

- Not for species with very low or large dispersal.
- Especially for species with intermediate dispersal abilities (relative to the habitat spatial pattern).

By using habitat availability metrics:

- There is no risk of overweighting connectivity considerations in the final conservation plan.
- No need to define *a priori* if conn. is important or not
- They provide a common currency / integrated analytical framework for both alternatives.

Saura & Rubio (2009) *Ecography* (in press)

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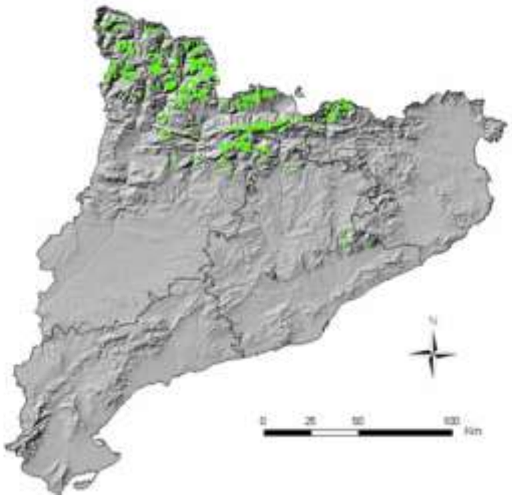
Application to capercaillie in NE Spain

1. Capercaillie habitat modeling

- Field surveys in 3,000 1 x 1 km cells from Catalan Breeding Bird Atlas (Estrada et al. 2004)
- Niche-based modeling (Maxent)
- Habitat = UTM 1x1 km cells with habitat suitability ≥ 0.2



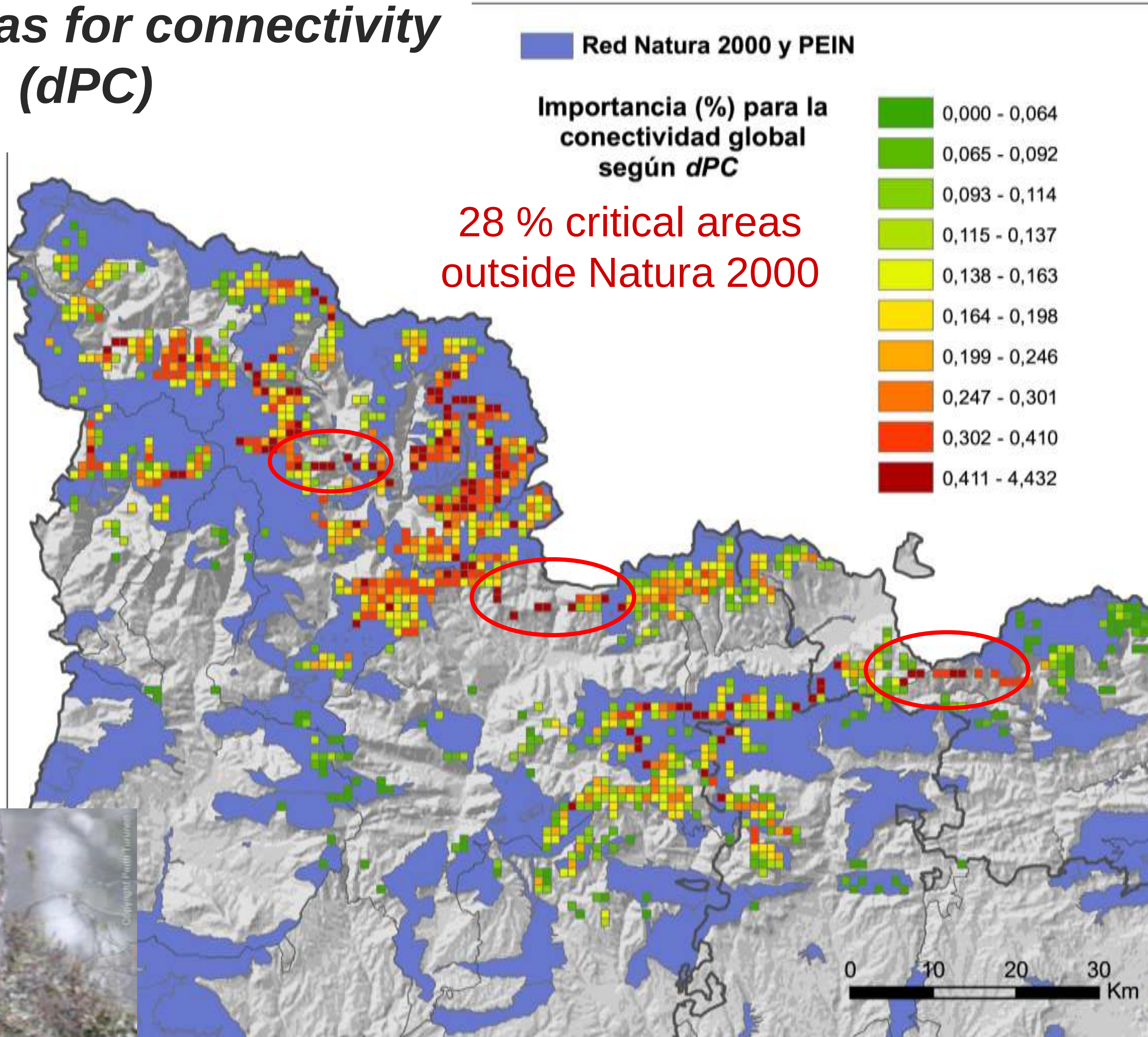
2. Dispersal

- Radiotracking in the Pyrenees
- Average dispersal distance 5 km

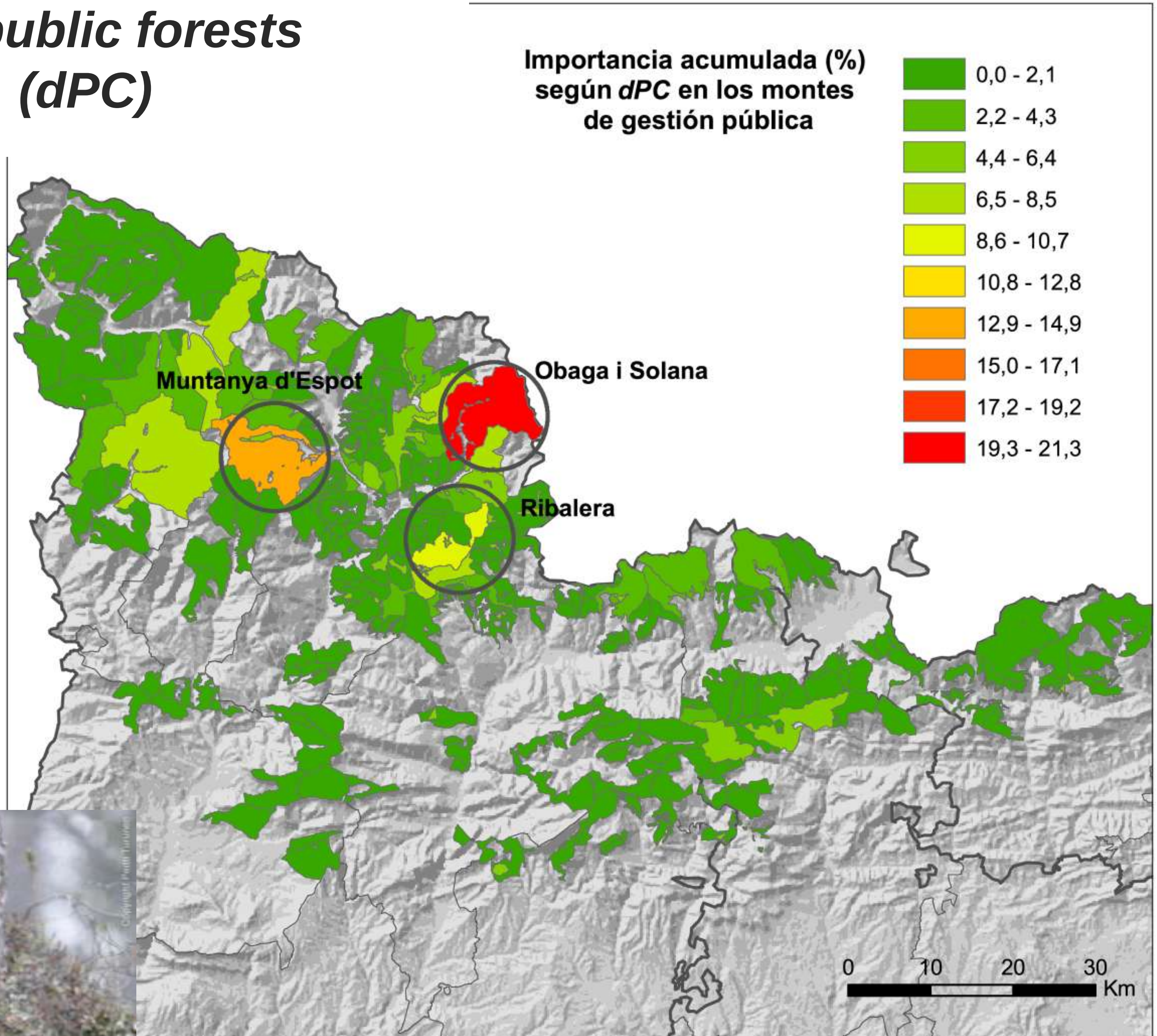
3. Connectivity analysis / tool:

- Conefor Sensinode (http://www.conefor.org)
- Probability of connectivity index (PC)

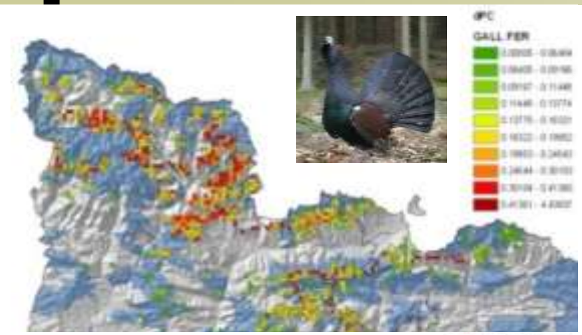
Critical areas for connectivity (dPC)

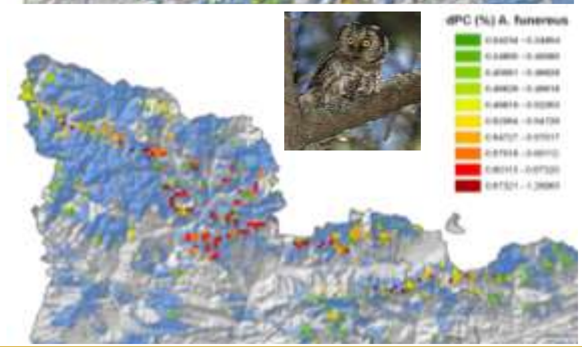


Key public forests (dPC)

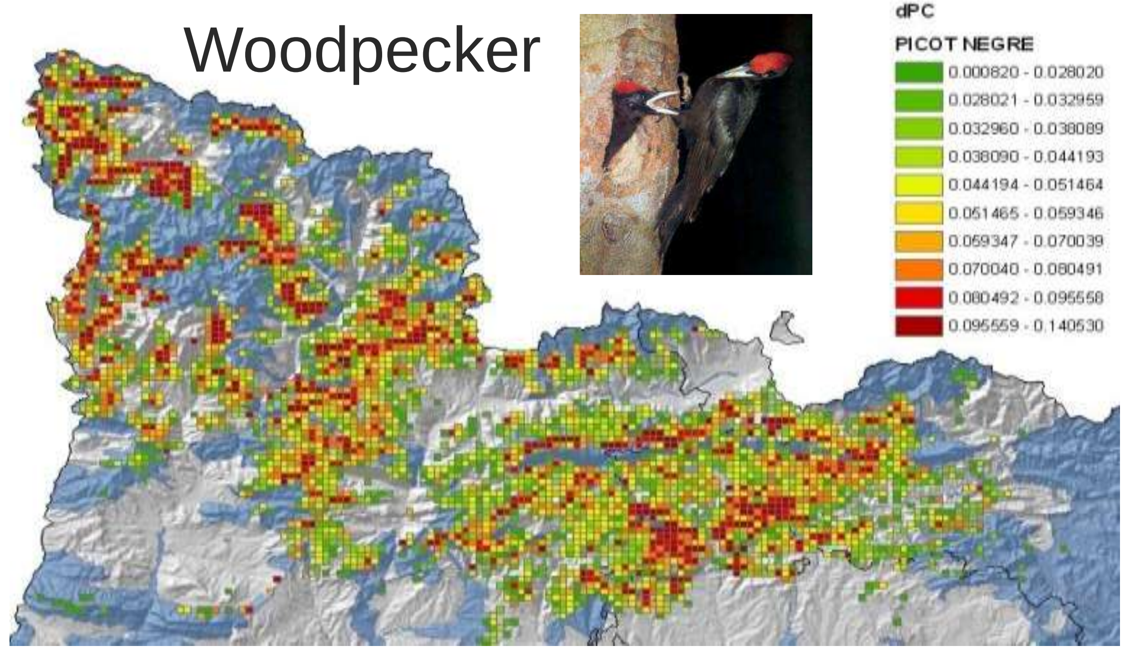


Example: endangered bird species in NE Spain





Woodpecker



	Capercaillie	Boreal owl	Woodpecker
Habitat pattern	Fragmented	Fragmented	≈ Continuous
Dispersal distance (km)	2.3	34.0	6.5
Max dPC	4.44	1.27	0.14
Proportion of dPC explained by intrinsic habitat attributes	20 %	75 %	98 %

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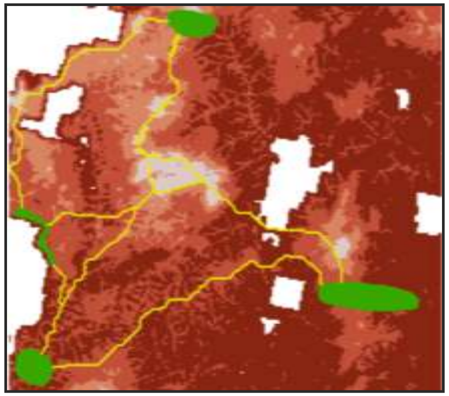
Incorporating the matrix resistance: the popular least cost modelling



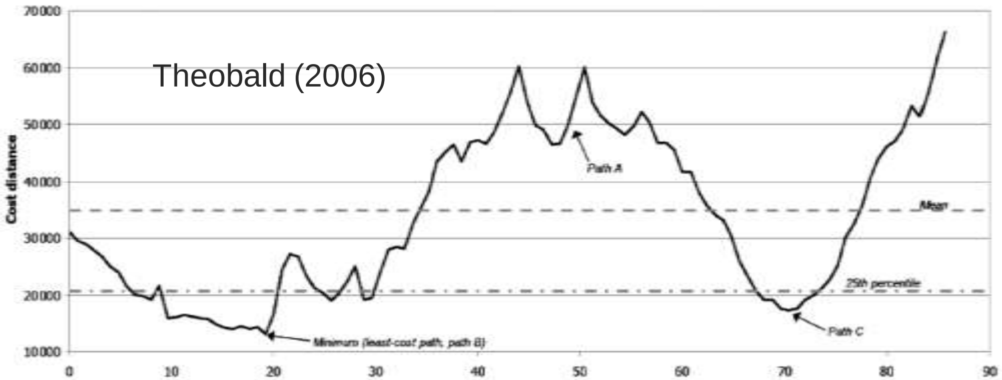
- Effective distances: resistance / friction surface + least cost analysis.
- Improvement over Euclidean distances.
- Tool: PathMatrix (Ray (2005))

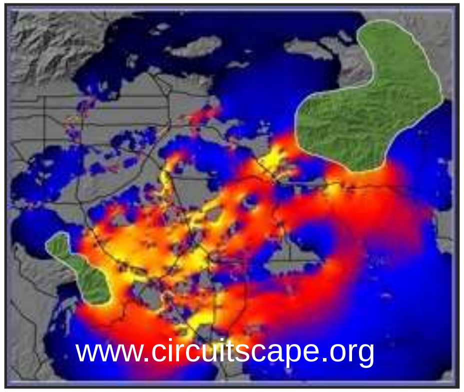
- But potential limitations:

1) A unique and optimal path identified. Rest of the matrix?
2) A pixel-wide path is enough as a corridor?
3) Arbitrary selection of friction values, lack of empirical data.
4) The least cost path is the optimal. But how good it is for actual species movement?
5) Computational bottlenecks

From a unique least-cost path to diffuse flows and multiple pathways

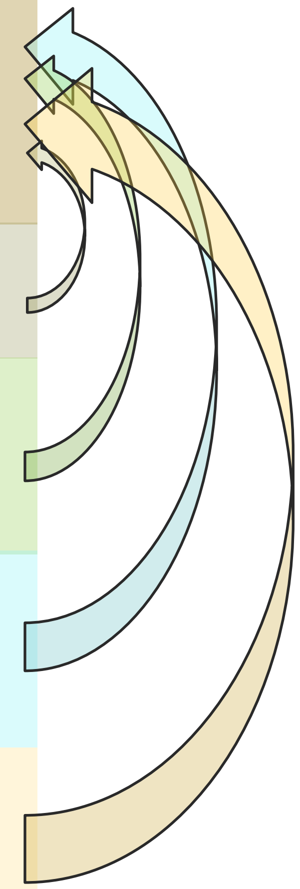
- Does an optimal path exist? Is that in fact used as such by the species? Contribution of multiple pathways and a larger matrix proportion?
- Theobald (2006): percentiles of cost distribution.
- Corridor Designer (Beier et al.): wide low (not just least) cost paths and frictions as inverse of habitat suitability (O'Brien et al., Chetkiewicz et al. 2006).
- Circuitscape (McRae et al. 2008): application of circuit theory, more related to actual gene flow and movement of random walkers in heterogeneous landscapes.





Summary of available relevant tools and their integration possibilities

- Conefor Sensinode: prioritizing landscape elements by their contribution to connectivity (fractions to be implemented soon).
- PathMatrix: connections as least cost paths.
- Corridor Designer: corridors as wide low cost bands and frictions from habitat models.
- Circuitscape: accounts for multiple paths to assess connection strength (circuit theory).
- Guidos: identification and mapping of spatial patterns and structural connectors.



To integrate connectivity in landscape planning…

1) Think of the landscape as a network of habitat units connected by links (graphs but not only).
2) Consider both intrapatch & interpatch connectivity (habitat availability) and the different roles of landscape elements.
3) Place connectivity within a broader context of planning and conservation alternatives.
4) Be aware of the scarcity of empirical information to model the landscape network and feed your connectivity analysis: use more complex models with care and rely in adaptable approaches if possible.
5) Test and use recent tools for integrating connectivity in landscape planning and ecological network design.